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XXVIII.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XXV.—NOTES ON EQUAL TEMPERAMENT AND THE CHARACTER OF MUSICAL KEYS.

By Charles R. Cross.

Communicated February 16, 1886.

The question as to how closely the tuner of a keyed instrument actually realizes the isotonic scale upon the instrument is one of much interest, regarding which there has hitherto been but little information accessible. Some very recent and valuable results of measurement will, however, be found on page 485 of the new edition of Mr. Ellis's translation of Helmholtz's *Tonempfindungen*, which should be compared with those which are given farther on in this paper.

The following measurements were made by Mr. William T. Miller and myself several years since, but have not been published hitherto, in the hope that they might be extended further, and to additional instruments. But this has not thus far proved feasible.

The best available instrument upon which to make such experiments appeared to be a good cabinet organ, and therefore a freshly tuned single-reed cabinet organ, made by Messrs. Mason and Hamlin, was hired of them for the purpose. The instrument was not tuned especially for us, however, but taken at random from the ware-rooms. The tonometer used was made by Koenig, and consisted of a set of thirteen forks tuned carefully to the isotonic scale, running from middle C, of 269.2 vibrations per second, to the octave of this. These forks, according to the maker, were correct within less than one tenth of a vibration. The notes of the cabinet organ throughout the octave, from C_3 to C_4, were carefully compared by the method of beats with the corresponding forks. The temperature varied but little from 78° F. during the experiments.

As considerable change in the rate of the reeds could be made by varying the strength of the air-pressure from the bellows, care was taken to avoid such variation as far as possible. It was found possible to reduce this to a very small amount, by always keeping the bellows full by gently and continually moving the feet. The same result could also be secured by filling the bellows full of air, and then allowing the pressure to diminish gradually, not forcing in air while the beats were being counted. This sufficed, however, only when the duration of the sound was brief.

In counting the beats we were usually able to count either ten or twenty in a series, and six or eight series were taken in succession before passing to the following note. The extreme difference in the duration of a series of ten or twenty beats was very rarely over five tenths of a second, and generally was less than this. The times were estimated by means of a stop-watch reading to eighths of a second.

Three complete and separate sets of comparisons were made at different dates between all the forks and the corresponding reeds of the cabinet organ. The rate of the highest note measured — that is, C_4, an octave above middle C — was in each case taken as that on which to construct the calculated scale, as experiment showed that the beats were better defined in the upper portions of the scale. The calculated vibration periods of the isotonic scale thus determined were compared with the periods of each one of the notes comprised in that scale as given by the organ, and the differences noted. The organ had, of course, been tuned from a C fork.

The following table gives the difference between the observed and calculated values of each note, assuming in each case, as just stated, that the scale was based on the high C. The differences are called positive when the observed value is the greater.

Name of Note.	Series A.	Series B.	Series C.
C	0.1	—0.1	0.4
C♯	0.1	—0.1	0.3
D	0.1	0.0	0.3
D♯	—0.7	—0.7	—0.4
E	—0.5	—0.1	0.0
F	—0.2	—0.1	0.1
F♯	—0.8	—0.5	—0.3
G	—0.2	—0.5	0.0
G♯	—0.8	—0.1	—0.7
A	—0.6	—0.5	—0.3
A♯	—0.7	—0.6	—0.2
B	—0.3	—0.4	—0.2
C	0.0	0.0	0.0

It appears from these figures that in no case is there a deviation of as much as one vibration per second in the scale as given by the organ from the true isotonic scale. It will also be observed that in each of the three series the errors in the upper portion of the scale are all negative, though this is probably accidental. The instrument was presumably tuned from a fork of approximately 536 vibrations per second.

There is a certain interest attaching to the foregoing measurements from their bearing on the origin and nature of the musical characteristics of different keys. It has always been difficult to account for the existence of such differences upon an equally-tempered instrument; and a favorite way of explaining it has been to suppose that the actual scale is not really an isotonic one, but that the scale of the tuner, as carried in his mind and secured on the instrument, is such as to give values to different notes that will really preserve their characteristics to the various keys. It is hard to understand how this can be the case when one considers the methods used by a tuner; and our own results, as do also those of Mr. Ellis, lead to the conclusion that the impression in question is an incorrect one. What is true of the cabinet organ and piano must also be true of other keyed instruments, as any noteworthy differences between instruments professing to be tuned to the same isotonic scale would immediately be noticed.

Helmholtz suggests that with stringed instruments differences of key may arise from the use of open or closed strings, or closed strings of different lengths, and, while denying the existence of such key-differences upon the organ, admits them to exist with the piano, and considers that they are there produced by difference of fingering, according to the position on the keyboard of the keys struck.

In order to test this, the following experiment was tried. Three pianos were taken, all of the same make and pattern, and of as nearly the same quality and loudness of tone as possible. The three instruments were originally at the same pitch. One of them was raised in pitch throughout the whole scale by half of an isotonic semitone, and a second was lowered by the same amount, while the third remained unaltered as a standard of comparison. Hence, the pianos of highest and lowest pitch were a semitone apart; that is, the scale was, so to speak, shifted upward by one key in one instrument with reference to the other. Hence, chords played upon the same notes of the keyboard would be of different pitch, although in the same musical key. On the other hand, chords composed of notes of exactly the same absolute pitch in the different instruments would be in different musical keys, since sounded by different groups of keys on the keyboard Now, if there is any characteristic difference of key under these circumstances due to fingering, as Helmholtz supposes, it should be possible to detect a difference of this nature according to which one of the two pianos the chords were sounded upon, these chords being of identical pitch in both. But neither in detached nor successive chords could we observe any difference whereby we could determine on which of the pianos these were played, provided the eyes were closed. There was a slight difference in quality of tone, which sometimes revealed the instrument, even when but a single key was struck ; but nothing beyond this. We were confirmed in our judgment by that of several musicians, who were afterwards invited to listen to the instruments. It would be interesting, however, to repeat the experiment, and obtain the opinions of a large number of musical experts.

The measurements cited go to show that any differences in key which exist on instruments tuned to the isotonic scale by a good tuner cannot be due to instinctive deviations from the mathematically perfect scale, whereby the alleged characteristic peculiarities of the different keys are preserved. And our experiments with the pianos seem to indicate that key-differences are not in this instrument caused by differences in fingering ; and, indeed, that any differences independent of pitch do not exist at all. Moreover, I doubt very much if the character of any harmony is changed in passing from a piano to an organ, and am inclined to believe that harmonies upon an organ give the same impression, so far as their key is concerned, as when played upon a piano, although, as Helmholtz remarks, in the case of the organ there can be no key-differences caused by differences in fingering. Still further, one can hardly see why the same characteristics of each key should be found on instruments of the violin and piano families, and on reeds and brass as well, if they owe their origin in each case to peculiarities inherent in the manner of playing each class of instrument.

I can speak but very diffidently upon a subject which is so largely one only to be appreciated and discussed by a musician ; but to me it seems extremely probable that there is no absolute character pertaining to any key. We notice the pitch of various passages, and, so far as we are habituated to any particular pitch, become accustomed to hear the notes of certain chords at that pitch, and so, on account of the peculiar character possessed by a group of notes having those particular pitches, we assign that character to the key to which the chord belongs. If the notes composing the chord are changed in absolute, but not in relative pitch, the change in the absolute pitch of the notes constituting the chord of the same name is noticed, and the changed effect attributed to some characteristic of the new key. And if, with a harmony which we have been accustomed to hear performed with all its notes at a tolerably definite standard pitch, the pitch of each note is changed by the same interval, and by an amount as great, for example, as a semitone, so that we realize the transposition, the harmony will seem to have a different character, which we attribute to its being in a different key.

I question very greatly if the impression which any of the instrumental music of Handel, Bach, or Mozart produces upon us, when played at the highest recent concert pitch, a markedly different effect from that which was produced when the low pitch at which those masters wrote was in vogue. Of course, merely noticing a change in character, which we may attribute to change in key, when the pitch is intentionally lowered a semitone, would prove nothing, as any ear keen enough to notice the change would carry the recollection of the high pitch at which it had usually been heard.

In view of the fact that music of the most varied characteristics has been written in the same keys, it is hard to understand how any such inherent character as is popularly imagined can attach to them. It seems much more likely that the great success of some eminent composer in writing music of a particular kind in a certain key has tended to stamp that character upon that key, in the minds of musicians; and later composers may even have been led to choose such a key from its imagined superiority for their purposes.

Rogers Laboratory of Physics,
February, 1886.